Grasslands Soils

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INTRODUCTION

Soil science developed in recent times in response to problems. In Europe during the 1800s, food shortages, social upheavals, and declining soil productivity brought about the need to study soil to improve and increase its productivity. At the same time, in Russia, a need arose to administer and manage geographically diverse soil resources. Russia had large areas of fertile, productive soils unlike those in Europe. As a result, Russian scientists developed an inventory of agricultural resources and determined the factors causing soils to vary across Russia. Soils were found to have relationships with climatic and vegetative zones.[1] It is from these concepts that the living soil individual was developed. Soil is a natural body and not a geologic formation. With time, soil develops from the parent material under the influence of the climate, vegetation, and topography (relief). These five factors of soil formation are interdependent and not independent. Changing one soil-forming factor often changes other soil-forming factors. Changing any one, some, or all of the soil-forming factors causes differences in soils and soil profiles.[2]

Soils and plants interact and evolve together forming different ecosystems. These soil–plant relationships are often most strongly expressed when native vegetation is present. The soils in grasslands, a major ecosystem, are very different from other soils due to this interaction.

IMPORTANCE, LOCATION, AND EXTENT OF GRASSLAND SOILS

Grassland soils have thick, dark-colored, humus-rich, surface horizons or layers and are some of the most productive soils in the world. These soils occupy about 7% of the world's land area (Table 1). The majority of grassland soils occur in temperate (3.4%) and boreal (3.2%) regions.[3] These soils are the dominant food- and fiber-producing soils in subhumid and semiarid regions because of favorable soil properties and climatic conditions. The world's breadbaskets (e.g., U.S. Midwest and Great Plains prairies; Canadian prairie provinces of Manitoba and Saskatchewan; the pampas of Argentina, Paraguay, and Uruguay; and the steppe regions of Europe, Russia, Mongolia, and Northern China) are dominated by grassland soils (Fig. 1). The largest grassland area in the world is found in Kazakhstan, Russia, and the Ukraine. Generally, small grains and grain sorghum are raised in the drier grassland regions. The warmer, humid grasslands are better suited for row crops like maize (corn) and soybeans. Where slopes are too great for cultivation or the climate is not favorable, grassland soils are used for pasture and rangeland. Native grassland types include: desert grasslands, <15 cm high; short-grass prairie, 15–30 cm high; mid-grass prairie, 30–100 cm high; and tall-grass prairie, 1–3 m high.[4]

Grassland soils (e.g., Mollisols) are very extensive in the U.S. (Fig. 2), especially the Midwest and Great Plains. They occupy about 21.5% of the U.S. land area,[3] more than any other soil ecosystem.

Grasslands tend to occur in subhumid to semiarid regions, where average annual precipitation ranges from 20 to 90 cm and average annual temperatures range from 0 to 32°C.[5] Grasslands tend to be located in areas between deserts (e.g., Aridisols) and forested (e.g., Alfisols) areas.[3] Different climates with similar effective annual precipitation levels (e.g., prairies of California and western Kansas) give rise to grassland soils with similar properties.[6] Soil texture and topography does modify the boundaries between prairie, forest, and desert areas (e.g., sandy, south-facing slopes are drier than loamy, north-facing slopes).[7]

PROPERTIES OF GRASSLAND SOILS

Soils that form under grass vegetation have unique soil properties and characteristics (Table 2). Grassland soils (e.g., Houdek soil—fine-loamy, mixed, superactive, mesic Typic Argiustoll) have thick, soft, dark-colored, moderately high organic carbon-containing A horizons (e.g., 0.5–10% organic carbon) with developed structure (e.g., mollic surface). Granular structure is most common in surface horizons with blocky (humid areas) and prismatic (semiarid areas) structure present in B horizons. Cultivation often causes granular surface soil structure to change to subangular blocky.[9] Grassland soils have sufficient strength to support grazing livestock and normal cultivational activity. The dark-colored A horizon

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Table 1 Global grassland soil distribution (based on ice-free land)

Continent/region	Area (km^2)	Area (% of region)	Area (% of world's grasslands)	Area (% of world's total area)
Africa	76,911	0.26	0.84	0.06
Asia	4,041,017	8.45	43.90	3.10
Australia/Oceania	103,569	1.31	1.13	0.08
Central America	32,302	4.64	0.35	0.02
Europe	724,280	12.62	7.87	0.56
North America	3,230,829	15.57	35.10	2.48
South America	994,431	5.67	10.81	0.76
Total	9,203,339		100.00	7.06

(From Refs.[3,20], and unpublished data from P. Reich, USDA–NRCS, World Soil Resources Division.)

slowly changes into a B horizon in most prairie-derived soils (Fig. 3).

The Houdek Bt horizon has developed structure and evidence of clay illuviation (Table 2). Clay illuviation is much less than that found in comparable forested soils. Base saturation and soil pH are high in all layers of most grassland soils. Divalent cations, especially Ca^{2+}, dominate the soil-cation exchange sites. Most grassland soils have smectite (2 : 1 lattice silicate clay minerals) present in the clay fraction, and textures are usually finer than loamy fine sand.[10] The average cation-exchange capacity of the soil solum is at least 15 $cmol_c\,kg^{-1}$ but averages 25–35 $cmol_c\,kg^{-1}$. Grassland soils can have many types of B horizons. Soils of the steppes tend to have horizons of lime accumulation (Bk in Fig. 3), whereas the grassland soils in humid areas tend to lack horizons of lime accumulation but have argillic, Bt, horizons. Some grassland soils have pans (e.g., duripans, petrocalcic layers), and some have strongly developed eluvial, E, horizons (e.g., albic). Still other grassland soils have only weakly developed B horizons (Bw and Bg) or no B horizon at all.

GENESIS OF GRASSLAND SOILS

The genesis of grassland soils is strongly dependent on the vegetation. Grasses, a source of organic matter and nutrient cycling, provide these two key components to the soil body. The principal process in grassland genesis is the accumulation of high base-content humus in the soil from the dense grass root systems near the soil surface.[2] Through the microbial decay of plant roots and plant tissue, organic matter is added to the soil surface and the soil profile in grasslands. Soil macrofauna (e.g., earthworms) incorporate the above-ground biomass tissue into the soil surface and help increase surface organic-carbon levels. Most grass roots are found in the top 30 cm of grassland soils.[11]

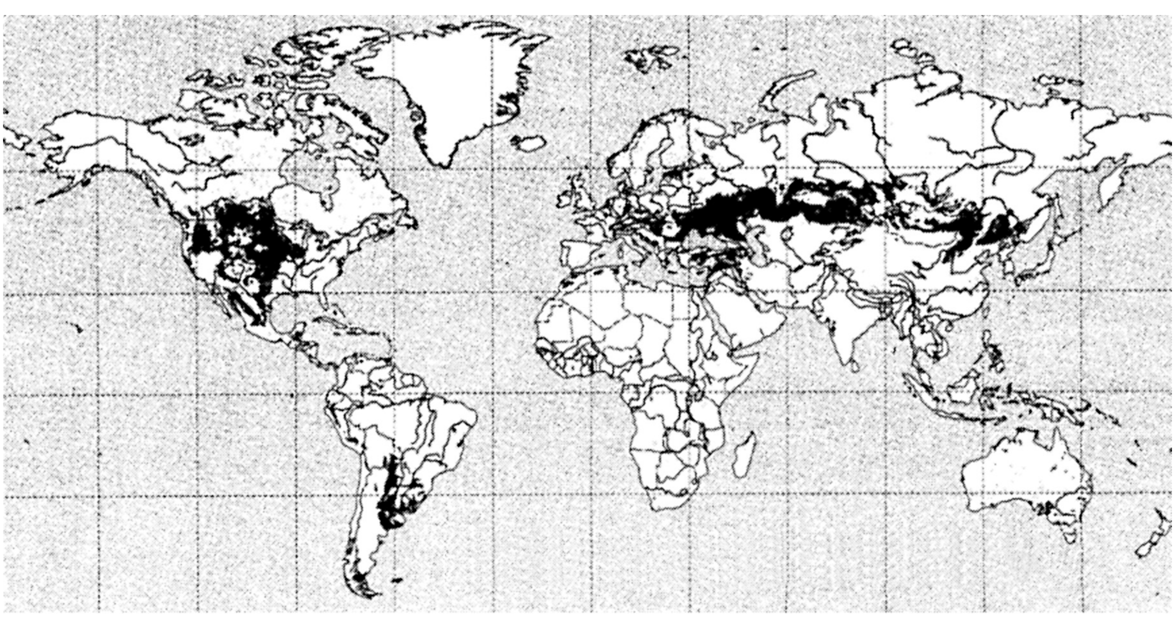

Fig. 1 Distribution of grassland soils (Mollisols) in the world. (From Refs.[3,20].)

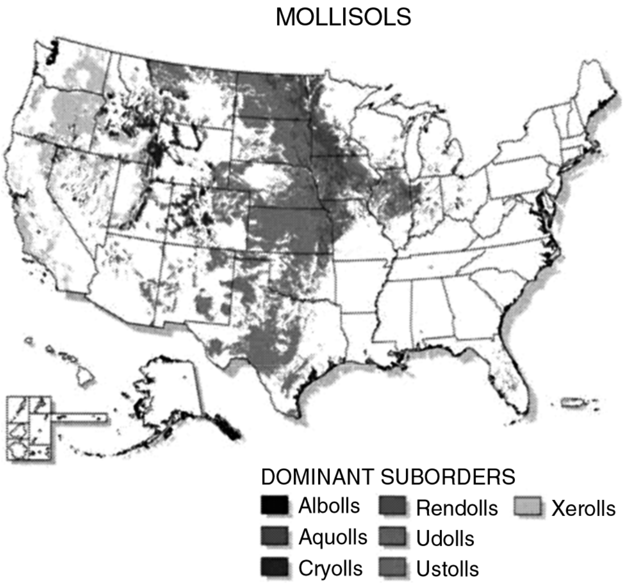

Fig. 2 Distribution of grassland soils (Mollisols) in the U.S. (From Ref.[21].)

Each year more than 50% of the biomass produced by unharvested grasses (nearly all of the above-ground biomass and about 30% of the below-surface biomass) is added to the soil.[12] The amount of above-ground grassland-biomass production can range from 1500 to 3500 kg ha^{-1} yr^{-1}, dry weight.[2] The amount of air-dry organic matter added per year can vary depending on climate conditions and vegetation type (e.g., 1250 kg ha^{-1} for humid prairie areas to 600 kg ha^{-1} for short- to mid-grass prairies).[13]

The distribution of organic carbon in grassland soils shows a gradual decline with increasing soil depth due to the gradual decline of fibrous grass roots and microbial activities with increasing soil depth (Table 2). This pattern of organic-carbon distribution is strikingly different from that in forest-derived soils where the organic carbon is high in a thin surface horizon and low in the rest of the soil. As a result, the structural stability of grassland soil peds tends to be stronger than nongrassland soil peds. Humus is not very water soluble, so it tends to stay in one location unless there is suspension or some mechanism for mechanical movement. The organic-carbon decline continues until the native rooting depth of the grasses is reached, and there is little or no organic carbon.

Grasses are large users of bases, especially calcium (Ca^{2+}). As a result, when grass residue is added to the soil surface, large amounts of cations (Ca^{2+}, Mg^{2+}, and K^{1+}) are brought to the surface, replacing cations lost by leaching and weathering activities. This results in higher soil pH values and base saturation throughout the profile (Table 1). The high concentration of bases help, along with the high content of shrinking–swelling silicate clay minerals and high humus levels, to form the granular structure that is common in grassland soils. In general, leaching under grass vegetation is minimal when compared to other types of vegetation (e.g., forest). Deep percolation of precipitation to the water table is not common, and deep leaching is not usually evident in most grassland soils. Grasses tend to utilize the water in the soil, preventing the deep leaching of nutrients. The grass plants keep recycling bases to the soil surface and this limits soil acidity, clay illuviation, and base-saturation reductions.

The development of textural horizons and silicate clay illuviation in grassland soils tends to happen in three steps.[14]

1. Removal of free carbonates—as long as free lime is present, the soil remains flocculated and little or no silicate clay will translocate.
2. Silicate clay formation and alteration—silicate clays are formed and altered as a result of weathering and soil genesis.
3. Silicate clay eluviation and illuviation—the fine silicate clays (<0.2 μm) move and precipitate out lower in the soil profile. The place where

Table 2 Selected soil properties of typical grassland (Houdek) soil

Horizon	Depth (in.)	Clay (%)	pH	Org. C (%)	Base saturation (%)	Structure	
						Grade	Shape
Houdek (grassland derived)							
Ap	0–6	22.0	6.2	4.6	84	Strong	Granular
Bt1	6–10	29.2	6.4	1.8	86	Strong	Subangular blocky
Bt2	10–18	26.5	7.0	1.1	95	Moderate	Prismatic
Bk1	18–28	25.9	8.2	0.5	100	Moderate	Prismatic
Bk2	28–40	24.8	8.4	0.3	100	Weak	Prismatic
C	40–80	23.2	8.4	0.2	100	Structureless	Massive

(From Ref.[8], http://www.statlab.iastate.edu/cgi-bin/osd/osdname.cgi?-P (accessed January 2001), and unpublished data from D.D. Malo, South Dakota State University.)

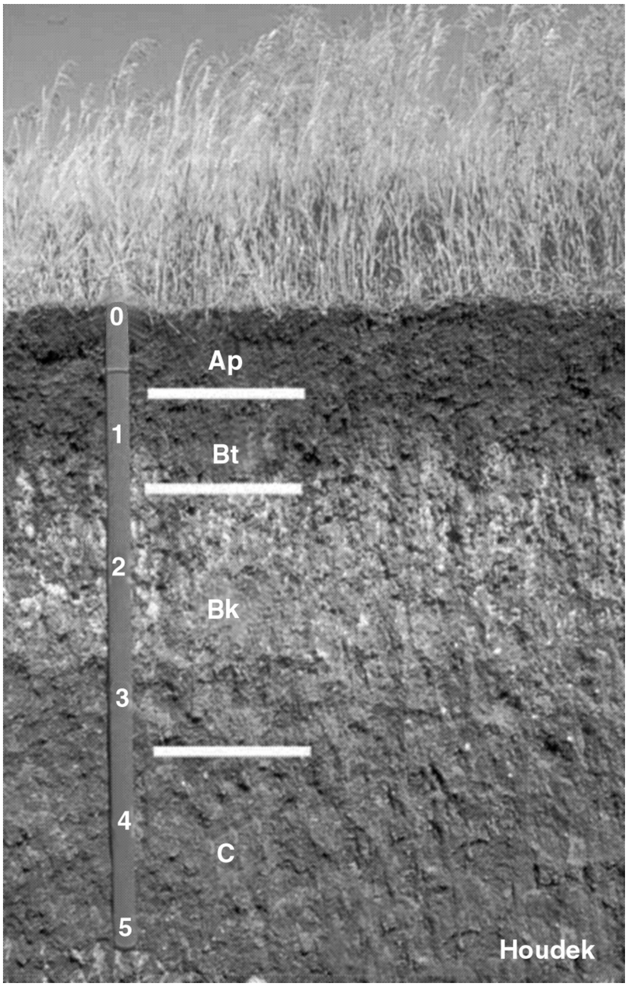

Fig. 3 Typical Great Plains grassland soil (Houdek—fine-loamy, mixed, superactive, mesic Typic Argiustoll). Scale is in feet.

> silicate clay illuviation occurs depends on pH, lime content, microbial activity, and moisture levels. Often, joint illuviation of both silicate clays and humus in grassland soils forms organo-argillans.

Another key indicator of soil genesis in grassland soils is phosphorus. Significant differences in phosphorus species have been noted in different grassland soils. Semiarid grasslands (Ustolls or Chestnut soils) had a larger percentage of calcium phosphates when compared to humid grasslands (Udolls or Chernozems), whereas humid grasslands had a higher percentage of iron phosphate.[15] Phosphorus distributions (total, organic, and inorganic) within the soil profile depend on horizon, lime illuviation, vegetation, and drainage.[14]

With cultivation in grassland soils, significant changes occur in the soil. Significant organic-carbon losses (>20% reduction in organic C levels after 20 yr of cultivation) and soil quality reductions occur.[5] The losses are most dramatic in the soil surface and diminish with increasing soil depth.[14]

Table 3 Soil classification of grassland soils

Soil or environmental conditions	Soil taxonomy	1938/1949 equivalents	FAO equivalents
Albic horizon	Alboll	Planosol	Planosol
Wet, hydric conditions	Aquoll	Gley	Gleysol
Very cold	Cryoll	Chernozem	Greyzem
Highly calcareous parent materials	Rendoll[a]	Rendzina	Rendzina
Humid	Udoll	Brunizem	Phaeozem
Moist spring/ dry summer	Ustoll	Chernozem, Chestnut	Chernozem, Kastanozem
Dry summer/ moist winter	Xeroll	Chestnut, Brown	Chernozem, Kastanozem

[a]Mostly formed under forest vegetation.
(From Refs.[3,16–18]. http://www/fao.org/waicent/faoinfo/agricult/agl/agll/key2soil.htm accessed January 2001.)

CLASSIFICATION OF GRASSLAND SOILS

The classification of grassland soils with various soil-classification systems is given in Table 3.

CONCLUSIONS

Throughout the world where grasslands are located, developed cultures exist. These soils are extremely productive and have allowed societies to flourish. About 40% of the grasslands are tall-grass prairies and 60% are short- and mid-grass steppes.[4] Grasslands have higher organism activity than most other soils.[5] Carbon sequestration in grasslands is critical to the global warming process. Grasslands are not only important for food and fiber production, but they have the potential to help solve one of the major problems facing human survival, global warming.[19] Grasslands are one of the most important ecosystems in the world.

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